Forward Modeling of Stratigraphic Sequences at Continental Margins

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LONG TERM GOALS

The goal of the Stratigraphy project of the STRATAFORM program is to understand the creation of the preserved stratigraphic record on continental shelves and slopes as the product of physical processes acting with spatial and temporal heterogeneities. I have been using numerical models to provide insight into the formation and preservation of stratigraphic sequences at margins. My goal has been to obtain a quantitative understanding of the interactions of environmental parameters and their influence on stratal architecture and facies distribution. I wish to be able decipher the stratigraphy on margins to read the geologic record of the past and predict future stratigraphy.

OBJECTIVES

I wish to understand how sea level and other factors control the formation of the stratigraphic record at margins. The stratigraphy at margins is packaged into unconformity-bound sequences whose form and lithology record the active processes at the margin. The influences of individual processes that create these sequences are only partly understood. My aim is to quantitatively determine the system response of margins to different forcing functions sufficiently to be able to both predict stratigraphy and invert observed sequence architecture for geologic history.

APPROACH

I am using numerical models as a tool to provide insight into the formation and preservation of stratigraphic sequences at continental margins. In conjunction with others, I have constructed an interactive computer model of stratigraphic sequences at continental margins. I am applying the model to the STRATAFORM field areas. The work is proceeding along three lines:

(1) Development of 2-D models focused on combining parameterizations of the dynamic sedimentologic and morphologic processes that control sediment deposition and erosion within a framework that accounts for geologic processes that effect accommodation .

(2) Numerical experimentation with the model to determine the stratigraphic consequences of the processes and parameter interactions. Examination of margin data to calibrate the model. Application of the model to the sequences in the field areas.

(3) Analysis of the geologic record sedimentary and geomorphologic processes in NJ and CA. A particular focus is backstripping to reconstruct the margin development. The modeling of the two margins provides constraints for unraveling the control of sequence development.

In this work I have collaborated with Greg Mountain on the interpretation and modeling of the New Jersey and northern California margins. I have been collaborating with most of the STRATAFORM modelers and others (Steckler et al, 2001) to incorporate and improve sediment transport models from the coastal plain to the continental rise. I am working with James Syvitski to coordinate our modeling efforts. I have coordinated with my co-chair, Jamie Austin to manage the stratigraphy project efforts.

WORK COMPLETED

The interactive stratigraphic modeling software, SEQUENCE5, is being upgraded to include multiple grain sizes. This effort will be completed shortly. The model uses a moving-boundary formulation (Swenson et al.., 2000; Steckler et al., 2001) with four units (coastal plain, shelf, upper slope and lower slope/rise) as its framework (Fig. 1). The positions of the boundaries and morphology of the margin all vary dynamically. Each regime is represented by a time-averaged differential equation that represents the net results of all processes. The upgrade to multigrain size has been done by making the advection-diffusion formulations for fluvial and marine deposition a function of the grainsize distrubution of the sediment supply and the bed. The fluvial formulation is being supplied by Chris Paola and the marine formulation is being supplied by Chris Reed. The marine parameterization and calibration are based on long-term runs of the SLICE hydrodynamic model (see Swift annual report for more details). In addition, the shelf module now includes a sub-grid scale routine, FACIES, that predicts statistical facies parameters. This program, developed under Don Swift at ODU, has been modified to run as a subroutine in SEQUENCE5 by Steve Parsons.

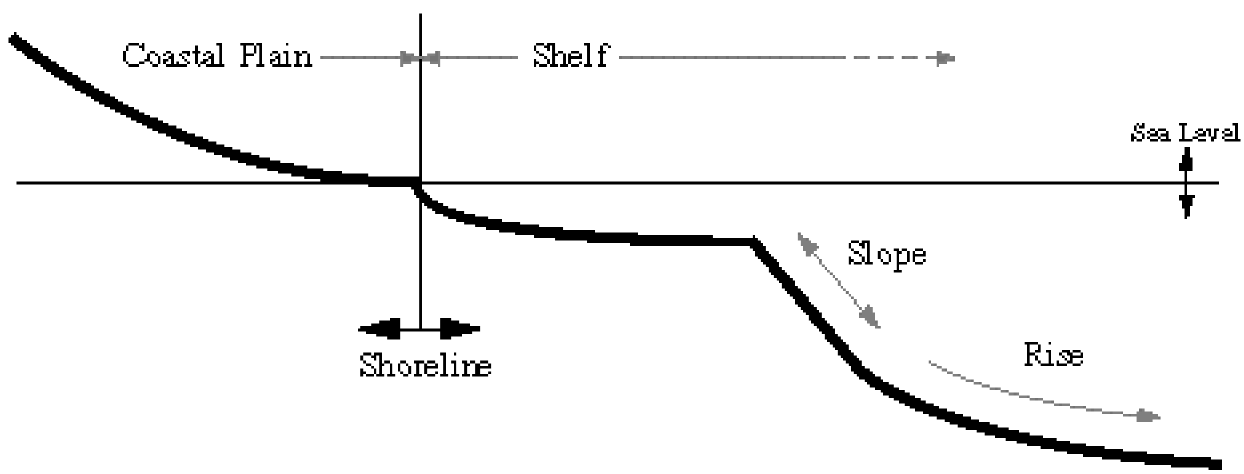

Figure 2. Conceptual diagram showing the components of the sediment transport/deposition modules in SEQUENCE4. The models includes coastal plain, shelf, slope and rise regimes. The boundary between the nonmarine coastal plain and marine shelf deposition is a moving boundary that tracks the shoreline. Shelf deposition tails off as water depth increases. Gravitational slope processes are invoked where profile meets threshold criteria. These sediments are transported seaward and deposited on the rise as turbidites. Multiple invocations of slope and rise algorithms are possible where clinoforms produce multiple breaks in slope on the profile.

In addition, we have continued to perform sensitivity experiments to investigate the response of the model. We have also continued to apply SEQUENCE4 to modeling the sequence stratigraphic architecture of the New Jersey and Northern California margins. Simulations completed provide an explanation of the different sequence geometries of the two margins. New Jersey exhibiting prograding clinoforms while California exhibits fanning reflectors beneath the shelf.

RESULTS

The application of the model to the two field areas has provided an explanation for the different sequence geometry observed at the two margins. The New Jersey margin dominated by progradation clastic clinoform-shaped packages. This pattern is also seen at the West African margin (Lavier et al., 2001) and many other continental margins around the world. These clinoforms represent the filling of available accommodation space on the shelf by an increasing amount of terrigenous sediments since the Oligocene. The thickness of the progradational packages indicates that they built out over a preexisting deep ramp margin. The 5-600 m deep shelf edge of the preexisting Eocene margin has been confirmed by 2D backstripping. Comparison to other margins indicates that this pattern is widespread (Bartek et al., 1991) and indicates that in the Eocene many margins had carbonate ramp morphology with a shelf break at 500-600m depth (Fig 2; Steckler and Lavier, submitted). Then, large clastic clinoforms prograded over the former ramp to create the modern continental margin with a flat shelf and sharp shelf break at ~100 m depth. This transformation of margins from deep ramps to shallow shelf-break morphologies requires a major increase in terrigenous sediment flux. Thus, margin morphology has evolved with global climate since the Eocene (~40 Ma). Global cooling with an associated change in erosion and sedimentation transformed the shape of continental margins.

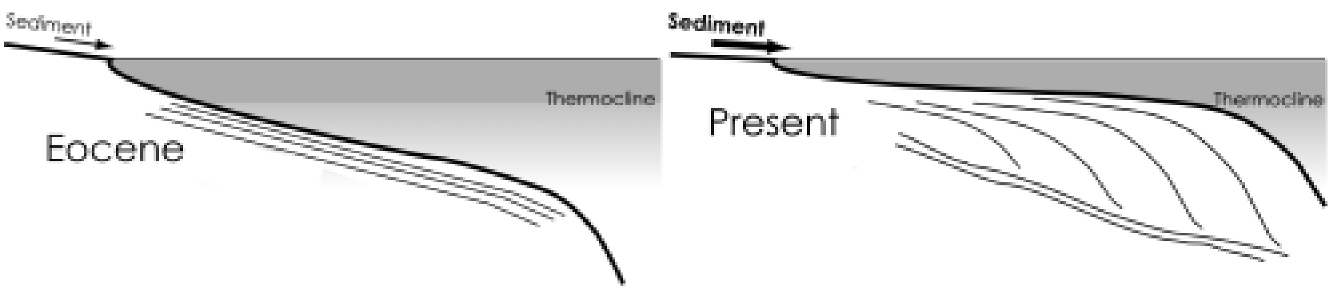

Figure 2. Cartoon illustrating the differences between Eocene ramp margins and present-day continental margins. In the Eocene, low sediment supply yield thin parallel strata, a deep shelf edge and a thermocline extends well onto the shelf. In the Neogene, higher sediment supply filled accommodation with prograding clinoforms and the thermocline intersects the margin near the shallower shelf edge.

The Eel River margin, unlike most others, does not contain prograding clinoforms. Rather, sets of seaward fanning sedimentary packages are observed beneath the shelf. Recent numerical modeling illuminates the origin of this contrasting architecture. Essentially, it is due to the rapid subsidence of the continental margin over the last 0.5 Ma (Gulick et al., 2002). This has resulted in a balance between the subsidence creating space and the sediments filling it (Fig. 3). This balance results in a long-term stationary shelf edge position. Within each sequence, the active depositional shelf and shoreline transgress and prograde (Fig. 3, 4). The net result is vertical aggradation of fan-shaped depositional packages consisting of transgressive and regressive strata. Beyond the filled accommodation space on the shelf, the margin drops off to the Eel plateau. Here, the subsidence exceeds the sediment accumulation yielding a progressing deepening of the plateau. The seaward edge of the plateau is the structurally-controlled edge of the forearc (Gulick et al., 2002).

Details of the sediment package for the last glacial cycle are shown in figure 4,.which shows the results for a stratigraphic simulation in the Eel River basin. The simulation was run using the relatively steep dips of this margin, rapid subsidence, high sediment supply and a sea level curve for the last 125ka. The complex multistage sea level fall from Stage 5 (125 ka) to Stage 2 (18 Ka) produces a series of progradational packages. Considerable erosion leaves a very incomplete section with numerous erosion surfaces. The large sea level rise since the last glacial maximum has covered the entire section with a smooth marine transgressive drape. The results are compared to a seismic line through the Freshwater Syncline that appears to image patterns consistent with the model predictions. The section shows a series of strong slightly fanning reflectors on the shelf, topped by the relatively transparent Holocene transgressive drape. Within these packages are series of more steeply dipping reflectors that I interpret to correspond to prograding shorefaces and other more steeply dipping interfaces in the model. I expect that the each of the multiple 100-ky cycles seen in Figure 3 is actually contains of the type of complex stratal relationships simulated in Figure 4.

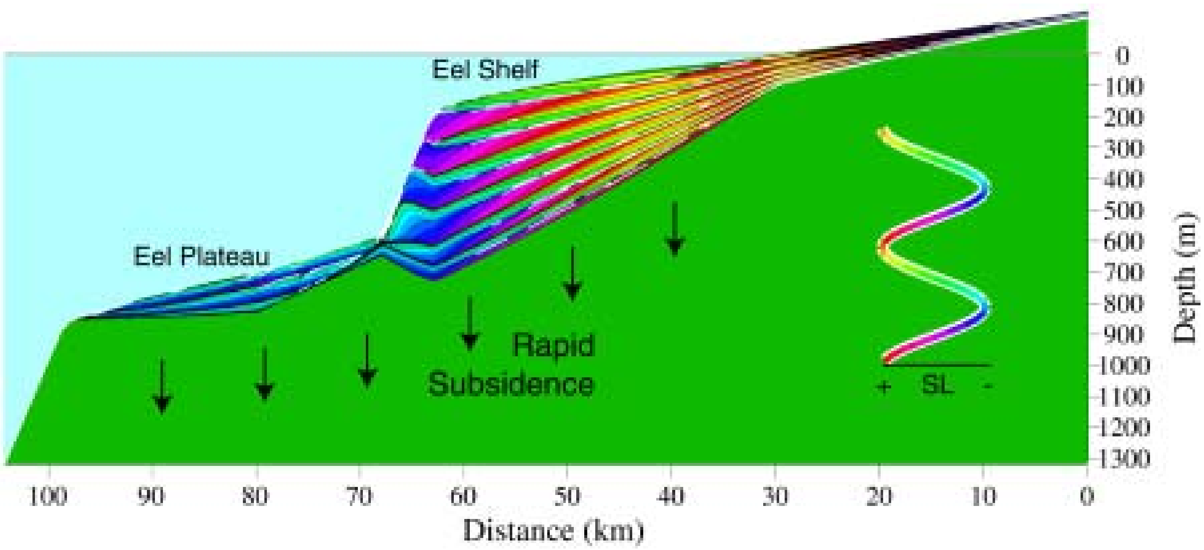

Figure 3. Cross section of the Eel margin generated by SEQUENCE. The figure shows a fanning set of aggradational sequences formed by 100-ky sea level cycles that comprise the Eel shelf. Beyond the 30-km wide shelf, the margin drops off to the 600-800 m deep Eel plateau before reaching a second break-in-slope. This slope continues to the deep oceanic basin.

IMPACT/APPLICATIONS

The fully-dynamic version of SEQUENCE is able to realistically deal with changes in sediment supply and slope failure during model runs. This has permitted more accurate prediction of the long-term morphodynamic response of margins to environmental change and more accurate predictions of stratigraphy. The apparent lack of clinoforms at the Eel river margin is finally explained – the entire shelf is a single large clinoform. Thus, the model is providing new predictions that correspond to observed features. The multigrain size version that is being completed will add a new dimension to the modeling effort. It will be able to better represent differences between margins due to sediment type (i.e., morphology and stratigraphy from coarse vs. fine grained sediments). It will allow better comparison to well data and better constrain model parameters. Characterization of the lithology will also enable calculation of seismic response of the model for more direct comparison to seismic data.

The changes in continental margin morphology and sediment supply seen at New Jersey appear to be widespread and apply to other margins. They are hypothesized as being related to the climatic changes of the Cenozoic. I conclude that widespread changes in morphology and sediment supply at margins during the Tertiary are related to global climate. These findings will enable better prediction of the stratigraphy at other margins.

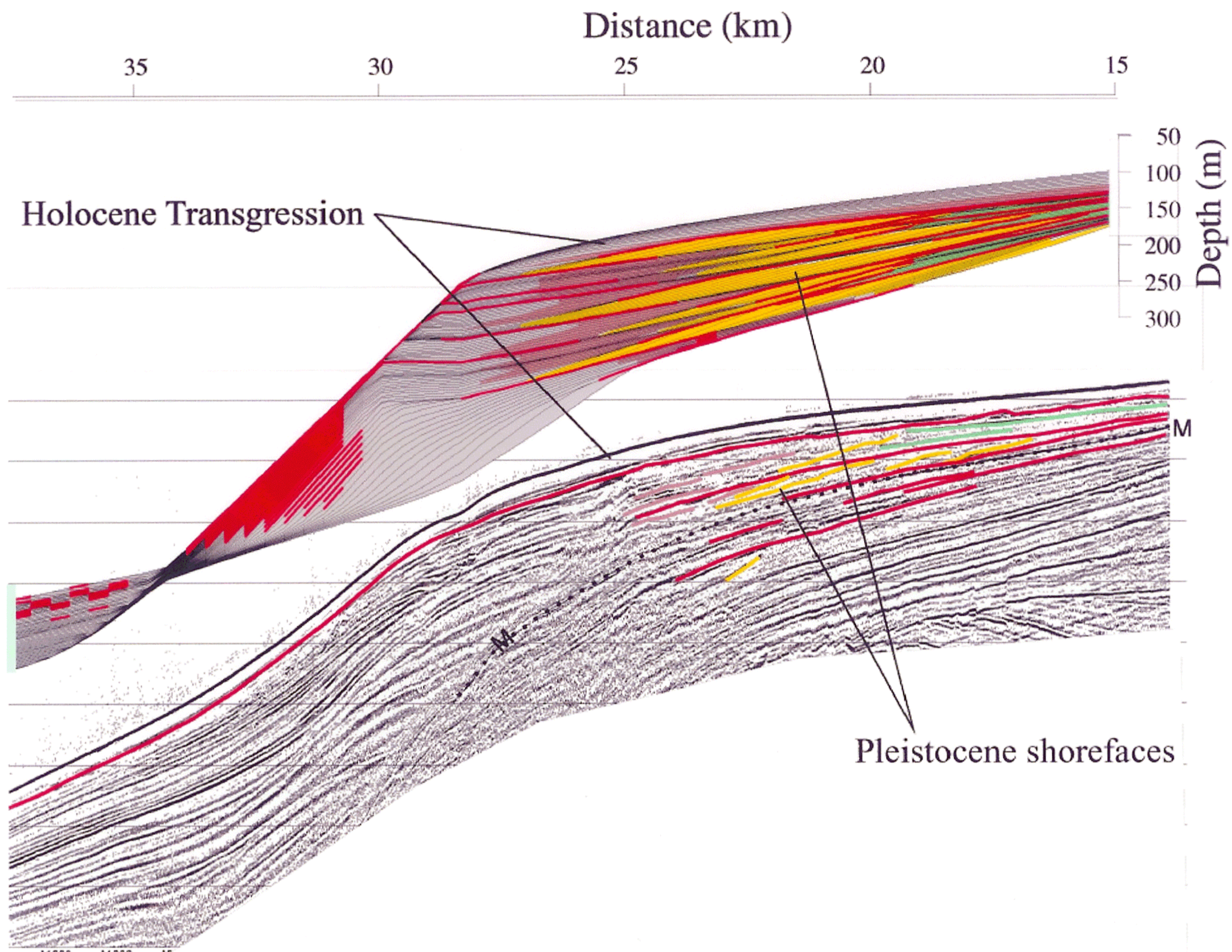

Figure 4. Comparison of model simulation to seismic line from the Eel River basin. The model on the top shows fanning progradational packages formed during the multistage sea level fall covered by a Holocene drape. Time lines are drawn every 1000y. Strata are colored green-nonmarine, yellow-shoreface, maroon-shelf and gray-slope/rise. Unconformities are heavy red lines. Below, is R/V Wecoma line 83, which exhibits a similar pattern of reflectors. These have been interpreted in colors corresponding to those in the model.

TRANSITIONS

Software is being used/installed at several other universities for both STRATAFORM and other sequence stratigraphic investigations.

RELATED PROJECTS

The West African margin (Lavier et al., 2001) and other margins around the world show similar sequence architectures as the NJ margin and are amenable to similar analyses. SEQUENCE has been used to model the Ganges-Brahmaputra Delta. This largest delta in the world differs from most others because large temporal changes in sediment supply halted the Holocene transgression during the rapid sea level rise and started progradation of the delta (Goodbred et al., in press). SEQUENCE will be used to model the Rhone continental margin by Marina Rabineau in EuroSTRATAFORM.

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PATENTS

None.